

# Zeolite ceramsite cellular concrete

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When the natural zeolite ceramsite (NZC) is added to cellular concrete, using the natural-zeolite powder as a gas carrier, natural-zeolite ceramsite cellular concrete is formed. It is a new type of concrete. Its compressive strength at 28 days is 12-14 MPa, while its density is 900-1000 kg/m<sup>3</sup>. It has a double capillary structure of cellular concrete and ceramsite. The NZC absorbs water and its capillaries are full of water when the concrete is mixed. But after concrete hardening, the capillaries in the NZC undergo 'self-vacuumization' owing to dehydration, so that the adhesion between the ceramsite and cellular concrete is increased.

## Introduction

There are now three kinds of cellular concrete used in China: autoclaved aerated concrete (AAC), foam concrete and air-entrained concrete. Because of their poor properties, the latter two are seldom used. The yearly production capacity of AAC is over 4 000 000 m<sup>3</sup>. But owing to the shortage of aluminium powder, only 2 000 000 m<sup>3</sup> of AAC are produced. In this study, a new kind of cellular concrete, namely natural-zeolite ceramsite cellular concrete (NZCCC), has been produced by adding the natural-zeolite ceramsite (NZC) to cellular concrete (CC), using the natural zeolite as a gas carrier, as shown in Fig. 1. After standard curing for 28 days, the compressive strength of NZCCC reaches 12-14 MPa with a density of only 900-1000 kg/m<sup>3</sup>; the strength is much higher than 5-7 MPa, the compressive strength of normal CC with a density of 700-900 kg/m<sup>3</sup>. In this paper, the strengthening effect of NZC on cellular concrete and its mechanism are described.

## Materials used in this study

### Cement

The Portland cement was made in Japan. Its specific surface area was 3320 cm<sup>2</sup>/g, and the strength grade was 410 by the JIS standard.

### Natural-zeolite powder used as air-entraining agent (NZAE)

The NZAE was made by calcining the natural-zeolite powder at 550°C for 1 h and then cooling it in a desiccator. This cooling method was used on a laboratory scale. In industrial production, the calcined NZAE is cooled in air. The chemical composition, size distribution curve and X-ray diffraction (XRD) curve of the NZAE are shown in Table 1, Fig. 2 and Fig. 3, respectively. An optical micrograph of the natural zeolite is shown in Fig. 4.

The natural-zeolite powder, which had been dehydrated at 350°C and then cooled to ambient temperature, was put into water to measure the volume of air evolved from it. The result was 4.2 cm<sup>3</sup>/g.

### The natural zeolite

The natural zeolite used in these experiments was ceramsite (NZC). Its bulk density, apparent specific gravity, compressive strength and water absorption were approximately 500 kg/m<sup>3</sup>, 1.0 g/cm<sup>3</sup>, 5 MPa and 2.0%, respectively.

## Experimental programme

The experiments were divided into four series, shown in Table 2.

## Experimental details

The size of each CC specimen was 5 cm dia. × 10 cm in series 1 and 10 cm dia. × 20 cm in series 2

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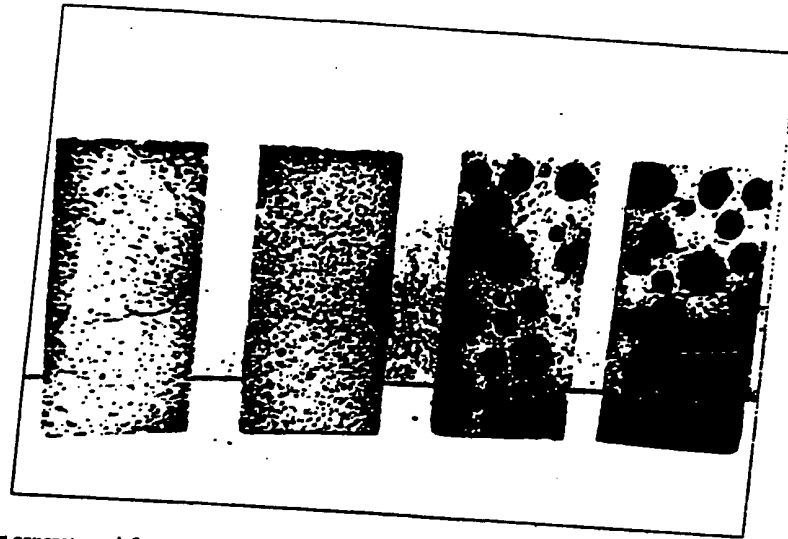


Fig. 1. (a) Cellular concrete and (b) NZC cellular concrete

Table 1. The chemical composition of NZAE: mass %

SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O + Na <sub>2</sub> O	Loss on ignition
66.96	12.55	1.85	1.92	0.47	5.22	11.02

and 3. In series 1 and 2 of the experiments, all the materials were manually mixed, but in series 3 they were mixed by a forced mixer, cast into moulds and vibrated. The moulds were removed one day after casting and then the specimens were immersed in water for 27 days. The curing temperatures for the three series were all 25°C. The final size of the specimens in series 4 was 10 × 10 × 10 cm. The materials were mixed in a forced mixer and then cast into moulds and vibrated. The specimen were demoulded one day after casting and cured in steam at 60°C for 1 h. Then the specimens, whose original size was 100 × 100 × 10 cm, were cut into specimens of size 10 × 10 × 10 cm. Half of the specimens were cured in water at a temperature of 25°C for 28 days and the other half were autoclaved at 180°C and 10 atm for 10 h.

## Results and discussion

The experimental results are summarized in Table 3.

From Table 3, it can be seen that for experimental series 1, the compressive strength of the CC increases with density, but decreases with  $w/(c + \text{NZAE})$ . The results of experimental series 2 can be plotted as in Fig. 5.

From Fig. 5 it can be seen that when  $c/\text{NZAE} = 9$  and  $w/(c + \text{NZAE})$  is about 0.35, the CC and NZCCC have almost the same strength of 23.5 MPa; such a

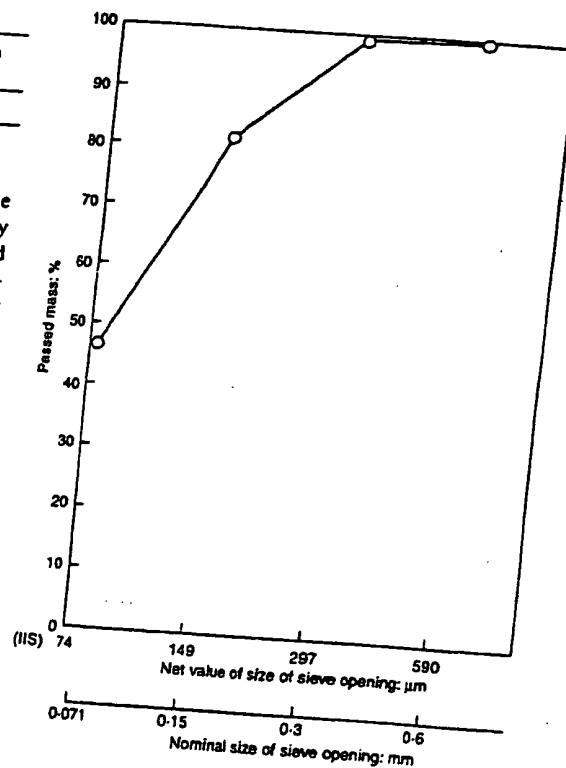


Fig. 2. Size distribution of NZAE

point is called an 'equal-strength point'. At this point the density of the CC is about  $1.3 \times 10^3 \text{ kg/m}^3$ , while the density of the NZCCC is only  $1.15 \times 10^3 \text{ kg/m}^3$ , lower than that of the CC by about 10%. When the  $w/(c + \text{NZAE})$  ratio increases, the strength of the

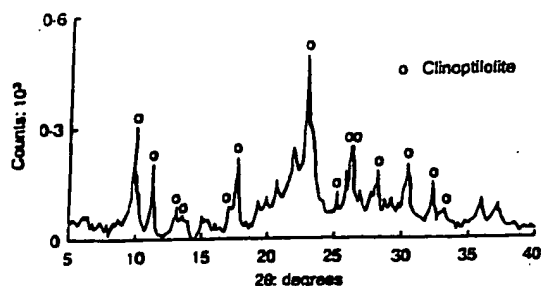


Fig. 3. XRD curve of NZAE

NZCCC becomes higher than that of the CC. Therefore, increasing the volume of NZC can result in a higher strength of the NZCCC.

It is also shown in Fig. 5 that when  $w/(c + \text{NZAE})$  is about 0.45 ( $c/\text{NZAE}$  is about 2.3), the CC and NZCCC have almost the same value of density. This point is called the 'equal-density point'. At this point, the compressive strength of the CC is 6.8 MPa, while the compressive strength of the NZCCC is 11.44 MPa, 67% higher than that of the CC. This also shows the strengthening effect of NZC. The compressive strength of the NZCCC is increased by the addition of NZC and



Fig. 4. Optical micrograph of natural zeolite

Table 2. Experimental programme

Series	No.	Mix proportions of CC			Volume ratio of NZC to CC	Curing condition	Aims
		Cement: %	NZAE: %	Water: %			
1	1	90	10	35	0	Water-cured at 25°C	Relationship between compressive strength and density of CC
	2	80	20	40	0		
	3	70	30	45	0		
	4	60	40	55	0		
	5	50	50	62	0		
2	6	90	10	35	30	Water-cured at 25°C	Changes of compressive strength of NZCCC for the same volume of NZC used in different densities of CC
	7	80	20	40	30		
	8	70	30	45	30		
	9	60	40	55	30		
	10	50	50	62	30		
3	11	80	20	40	0	Water-cured at 25°C	Changes of compressive strength of NZCCC for different volumes of NZC added in the same mix proportions of CC
	12	80	20	40	10		
	13	80	20	40	20		
	14	80	20	40	30		
	15	80	20	40	40		
	16	80	20	40	50		
4	17	80	20	40	40	Water-cured at 25°C	Effect of different curing conditions on compressive strength
	18	80	20	40	40	Autoclave-cured at 180°C and 10 atm and 10 h	

Table 3. Experimental results for CC and NZCCC

Series	No.	Density: kg/m <sup>3</sup>						Compressive strength: MPa		Autoclave-cured specimens			
		Removed from mould		After 28 days curing		Dry density		CC	NZCCC	Density: kg/m <sup>3</sup>		Compressive strength: MPa	
		CC	NZCCC	CC	NZCCC	CC	NZCCC			CC	NZCCC	CC	NZCCC
1	1	1660		1720		1300		22.4					
	2	1440		1550		1100		13.4					
	3	1280		1330		920		6.8					
	4	1150		1200		800		5.5					
	5	1010		1060		700		5.0					
2	6	1660	1520			1300	1160	23.4	23.4				
	7	1440	1370			1100	1030	13.4	17.4				
	8	1280	1330			920	970	6.8	11.4				
	9	1150	1220			800	870	5.5	9.0				
	10	1010	1100			700	790	5.0	7.5				
3	11		1380				1082		12.2/100*				
	12		1410				1090		16.5/135				
	13		1366				1066		16.5/135				
	14		1305				1005		16.6/136				
	15		1248				948		16.5/135				
	16		1251				950		19.5/160				
4	17					910	1080	9.5	15.5	953	953	7.1	15.0
	18												

\* The first number is the absolute value of the strength and the second number is the relative value of the strength.

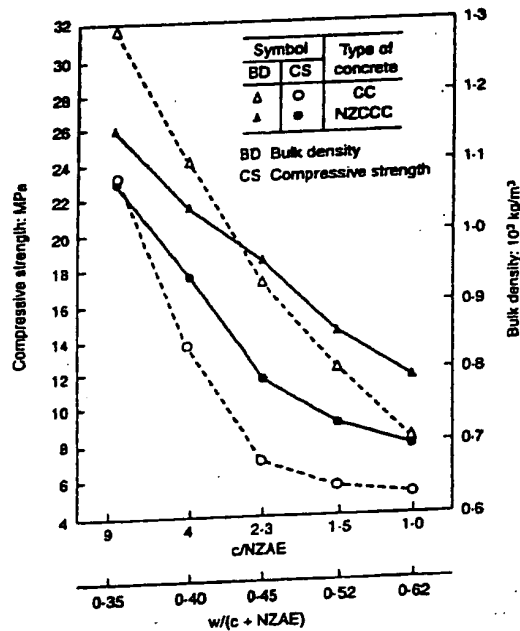


Fig. 5. Relationships between compressive strength, density and  $w/(c + \text{NZAE})$  for CC and NZCCC

can be further improved if the volume of NZC is made larger. Because the apparent specific gravity of NZC (about 1.0) is lower than that of the CC, a larger volume of NZC results in a lower density. The CC

cured in water has a strength 34% higher than the autoclaved CC. The NZCCCs cured in water and in the autoclave have similar strengths. In the autoclave-cured condition, the NZCCC has a strength 111% higher than the CC.

### The structure and strengthening mechanisms of NZCCC

Since NZCCC can be divided into CC and NZC, the microstructures of the CC and NZC should be analysed first before analysing the microstructure of the NZCCC.

#### The microstructure of CC

The cement paste expands in the presence of NZAE. Furthermore, NZAE can react with the  $\text{Ca}(\text{OH})_2$  from hydration of the cement to produce C-S-H. This improves the microstructure and strength of the CC.<sup>1,2</sup>

Figure 6 shows an SEM micrographs of water-cured CC containing NZAE at ages of 28 and 90 days. Figure 7 shows an XRD curve of a sample made from NZAE and  $\text{Ca}(\text{OH})_2$  and cured in water for 28 days.

#### The microstructure of NZC

The microstructure of NZC has already been described elsewhere.<sup>3</sup> The pores of NZC are spherical and discontinuous, as shown in Fig. 8.

#### The microstructure of NZCCC

Adding NZC to fresh CC (as shown in Fig. 1) makes NZCCC. The capillaries of NZC, which are full of air,

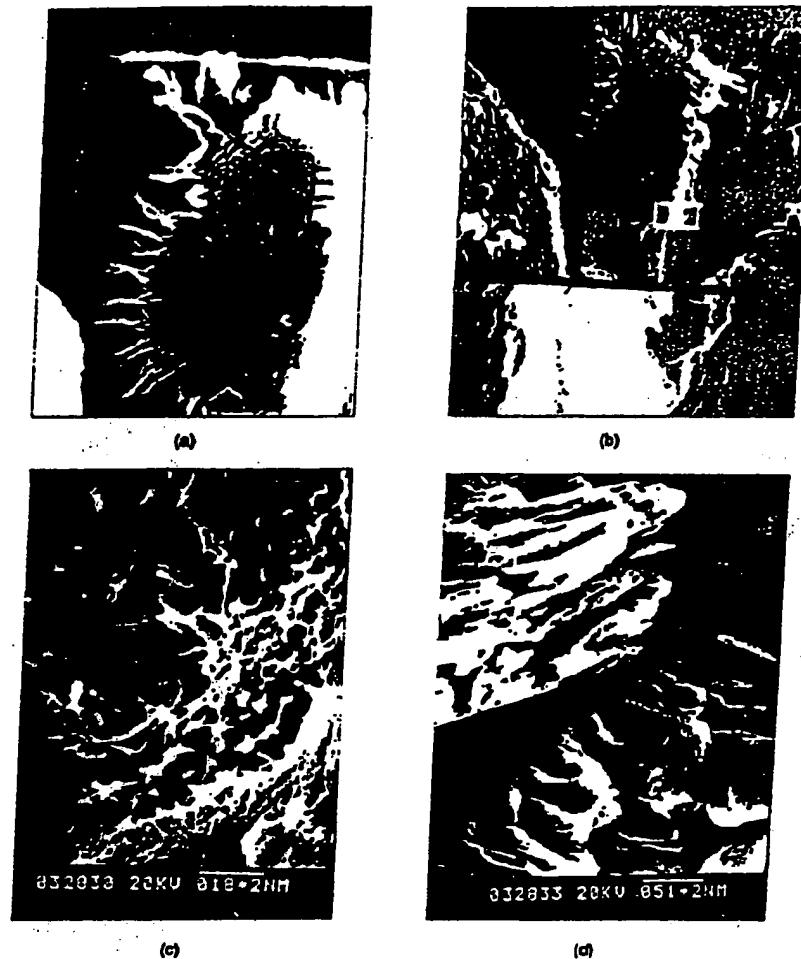


Fig. 6. SEM micrographs of CC air-entrained by NZAE: (a) air pore structure of CC (28 days); (b) enlargement of hydrated products in air pore structure (28 days); (c) air pore structure of CC (90 days); (d) enlargement of hydrated products in air pore structure (90 days)

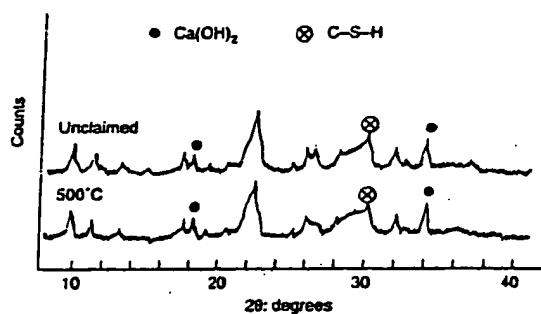


Fig. 7. XRD curve of sample made from NZAE and  $\text{Ca(OH)}_2$

will absorb water when it is mixed with fresh cement paste. Then closed air bubbles will form in the capillaries, with a pressure higher than normal atmospheric pressure. When the cement is setting and hardening,

the water absorbed by the NZC gradually transfers to the hardening paste, and at the same time, the capillary pressure drops to less than that of the atmosphere. This process is called 'self-vacuumization'. It can strengthen the interface between the NZC and cement paste and increase the strength of the NZCCC. Fig. 9 shows the capillary pressure, which changes with time. Fig. 10 shows an SEM micrograph of the interface structure of the NZCCC.

## Conclusions

Both cellular concrete (CC) and natural-zeolite ceramsite cellular concrete (NZCCC) are lightweight concretes. When natural-zeolite ceramsite (NZC) is added to CC, NZCCC is formed. The microstructure and

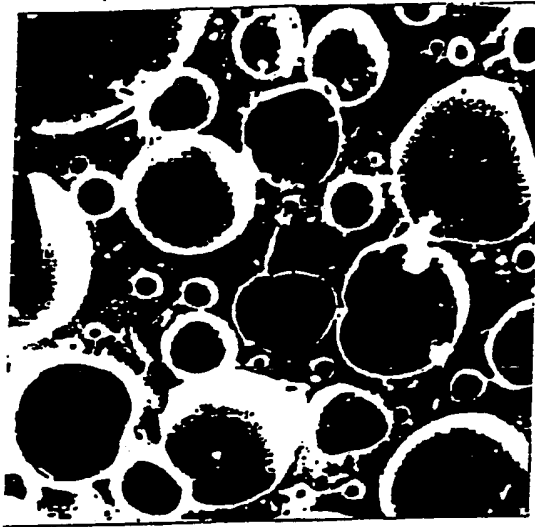


Fig. 8. SEM micrograph of ceramsite

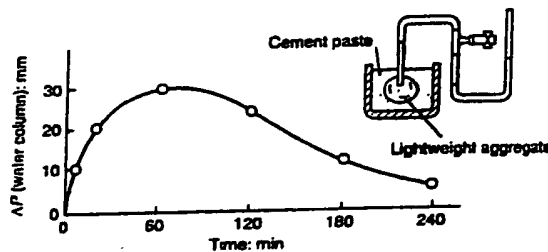


Fig. 9. Capillary pressure of NZC in cement paste

compressive strength of CC and NZCCC are different, so that their properties are also different.

There exist an 'equal-strength point' and an 'equal-density point' for CC and NZCCC. The strength of NZCCC is higher than that of CC at the 'equal-density point', while the density of NZCCC is lower than that of the corresponding CC at the 'equal-strength point'. This can be explained by the changes resulting from the NZC added.

NZAE can react with  $\text{Ca(OH)}_2$  from hydration to produce the C-S-H phase. The microstructure of the concrete improves with age. As a result, the strength of CC and NZCCC are both increased.

The NZC has a 'self-vacuumization' effect in concrete. This can strengthen the interface between the NZC and cement paste; consequently, the strength of the NZCCC is increased.

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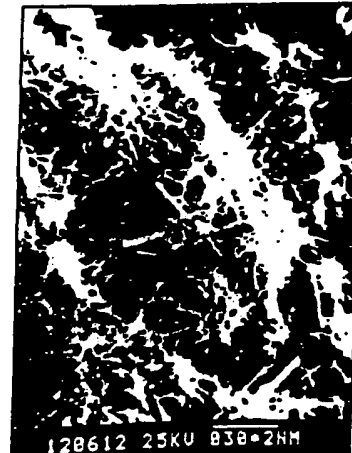


Fig. 10. SEM micrographs of interface structure of NZCCC: (a) interface between NZC and CC; (b) enlargement of CC on surface of NZC

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